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SECURITY CLASSIFICATION OF THIS PAGE

AD-A250 219

Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986

REPORT DOCUMENTATION PAGE

DTIC ELECTE MAY 19 1992 S A D

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Test Operations Procedure (TOP) 6-2-604	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Army Electronic Proving Ground 6b. OFFICE SYMBOL (If applicable) STEEP-TS-R	7a. NAME OF MONITORING ORGANIZATION US Army Test and Evaluation Command
6c. ADDRESS (City, State, and ZIP Code) Fort Huachuca, AZ 85613-7110	7b. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21005-5055
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Same as item 7a. 8b. OFFICE SYMBOL (If applicable) AMSTE-TC-D	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Same as item 7b.	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: AMCR 310-6 PROJECT NO.: TASK NO.: WORK UNIT ACCESSION NO: A248964

11. TITLE (Include Security Classification)
Antenna Pattern Measurement Facilities (U)

12. PERSONAL AUTHOR(S)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ______ TO ______	1992, April 15	52

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
09	03	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Outdoor Compact Range, Quiet Zone, Antenna Testing, Arc Range, Near Field, Far Field

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The test operations procedure (TOP) is an overview of procedures for testing antennas using the automated data acquisition and analysis system (ADAAS) at the Antenna Test Facility (ATF), US Army Electronic Proving Ground, Fort Huachuca, Arizona. The ATF has two test ranges: an outdoor compact range and an arc range. The Compact Range uses a parabolic reflector to collimate radio frequency energy in order to simulate far-field testing. A large hydraulic positioner moves the test antenna through azimuth and elevation arcs to allow testing of an entire hemisphere of coverage. The Arc Range operates in the near field using uncollimated RF. It uses a turntable to rotate the test item through the desired range of azimuth; a probe antenna moving along the vertical arc structure provides elevation coverage. The combination provides full hemispherical coverage. The TOP describes procedures for measuring antenna gain; locations of beams, lobes, and nulls; and other antenna characteristics. It contrasts the capabilities of the two ranges and provides guidelines to help the user select the right range for a particular test.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP 702
Test Operations Procedure 6-2-604
AD No. A248964

15 April 1992

ANTENNA PATTERN MEASUREMENT FACILITIES

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1. SCOPE

a. General. This TOP is an overview of procedures for testing antennas using the USAEPG automated data acquisition and analysis system (ADAAS) at the Antenna Test Facility (ATF), Fort Huachuca, Arizona. Included are procedures for far-field pattern measurements, gain determination, and data reduction. This material is written with the assumption that the reader is familiar with fundamental antenna measurement procedures and radio frequency (RF) principles. Detailed operating procedures, intended for use by the engineers and technicians who staff the facility, can be found in the applicable Range Operation and Maintenance Manuals.

b. Types of Tests. Most tests seek to compare the performance of a system to a given set of criteria. Measurements made at the ATF can directly address the following types of criteria:

Antenna gain
Location of main beam
Beamwidths
Locations and levels of sidelobes
Locations and depths of nulls
Secondary peaks
Multiple beams

In addition, data from the ATF can be further analyzed by examining the behavior of the above parameters with respect to frequency, configuration, or other test-specific variables.

2. FACILITIES AND INSTRUMENTATION

2.1 FACILITIES

a. Systems. The ATF ADAAS system at Fort Huachuca, Arizona consists of two primary antenna test ranges. An arc and turntable positioning system make up the Arc Range, and a highly accurate reflector and two-axis positioner comprise the newer Compact Range (figure 1). Although different in capabilities and physically separate, the Arc and the Compact Range may be regarded simply as two different instruments for measuring antenna performance. Both ranges feed data to the ADAAS for reduction, analysis, and presentation. They share a common control facility, in the form of a trailer situated in a revetment next to the Arc Range. They share the same staff of support engineers and technicians. A small assortment of airframes and test vehicles is available for use by either range should the actual host vehicle be unavailable for test. Tables 1 and 2 provide additional detail on range-specific and range-common equipment.

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b. Positioning Systems. Both ranges employ positioning systems designed to allow sampling of the fields radiated by an antenna on the surface of a sphere centered on the antenna. One hemisphere, either upper or lower, is measured at a time. The test vehicle is then turned over, if required, to allow data collection for the remaining hemisphere. Specific characteristics of the ranges' positioners are described below.

(1) Arc Range Positioner. The Arc Range provides hemispherical coverage by a combination of horizontal rotation of the antenna under test mounted on a turntable, and movement of a probe antenna along the vertical arc. The turntable has a maximum weight capacity of 60 tons, allowing the Arc Range to test large and massive vehicles.

(2) Compact Range Positioner. The Compact Range positioning system consists of a tiltable turntable supported approximately 42 feet high in the center of the quiet zone created by the reflector. The RF characteristics of this zone will be discussed later. The turntable rotates and tilts in order to provide hemispherical coverage. The turntable has a maximum weight capacity of 70 tons. This capacity allows the Compact Range to test a wide variety of vehicles, including the M1 Abrams Main Battle Tank and OV-1 Mohawk aircraft. Because the turntable tilts, test items must be securely mounted to it. Brackets must be specially designed for this physical requirement, as well as provide for electrical interfacing needed for the antenna under test.

2.2 INSTRUMENTATION

Tables 1 and 2 list and describe the instrumentation used by each range and the equipment common to both ranges. Each range is controlled independently, and each has its own RF system, but both feed a common computer for data reduction, analysis, and display.

TABLE 1. RANGE-SPECIFIC TEST INSTRUMENTATION AND EQUIPMENT

Arc Range	Compact Range
Microcomputer Instrumentation Controller: A DEC MicroVAX II microcomputer with a high-speed IEEE-488 interface controls all the IEEE-488 instrumentation on the Arc Range.	**Microcomputer Instrumentation Controller:** A DEC MicroVAX II microcomputer (separate from the one used with the arc) with a high-speed IEEE-488 interface controls all the IEEE-488 instrumentation on the Compact Range.
Positioner Control System: A Scientific Atlanta (SA) 2012A positioner programmer interfaces the IEEE-488 instrumentation bus to the SA 4180 positioner control systems. The positioner programmer allows manual or automated control of the arc probe antenna's elevation angle and the turntable's azimuth angle.	**Positioner Control System:** A Flam and Russell 85O2 positioner programmer interfaces the IEEE-488 instrumentation bus to the hydraulic interface unit (HIU) to operate the turntable azimuth and elevation axes (axes A and B). The system can operate an auxilliary positioner (axes C,D,E,or F). In this auxilliary mode the HIU becomes transparent to the system and utilizes a Scientific-Atlanta 4180 SCR unit as the axis driver/controller. The positioner programmer allows manual or automated control of the auxilliary positioner axes and of the hydraulic turntable elevation and azimuth angles.
RF Signal Generation: A Hewlett-Packard 8340B signal source generates fundamental RF signals from 10 MHz to 26.5 GHz. Maximum output power levels vary from +1 dBm to +12 dBm depending on frequency. The output level is adjustable from these maximums to a minimum of -110 dBm.	**RF Signal Generation:** A Hewlett-Packard 8340B signal source (separate from the one used with the arc) generates fundamental RF signals. From 6 GHz to 18 GHz the fundamental signal is amplified by a Hewlett-Packard 8349B microwave amplifier to provide a maximum output power level of approximately +19 dBm. From 18 GHz to 26.5 GHz the fundamental signal is routed through a Logimetrics TWT amplifier to provide a maximum output power level of approximately +31 dBm. From 26.5 GHz to 4O GHz the fundamental signal is routed through the 8349B amplifier to a Hewlett-Packard 83554A millimeter-wave source module and finally through the Logimetrics TWT amplifier to provide a maximum power output level of about +37 dBm. Output levels are adjustable. Near maximum levels are usually used in order to maximize the dynamic range of the test data.
RF Signal Receivers: A Scientific-Atlanta 1783 programmable microwave receiver serves as the range receiver for the Arc Range. The ATF has mixers and frequency converters to provide frequency coverage from 100 MHz to 18 GHz. A Scientific-Atlanta 1711 receiver is used in manual mode to provide extended frequency coverage from 25 MHz to 40 GHz.	**RF Signal Receiver:** A Hewlett-Packard 851OB network analyzer serves as the range receiver for the Compact Range. The 851OB commands the 834OB RF source and 8341B local oscillator (LO) source over the network analyzer system bus. RF and LO frequencies and power levels are determined during test definition and are dependent upon the frequency band of operation and mixer harmonic number.

TABLE 2. TEST INSTRUMENTATION AND EQUIPMENT COMMON TO THE ARC AND COMPACT RANGES

Minicomputer: A DEC VAX11/751 minicomputer manages the database of test specifications and acquired data for both antenna ranges. The minicomputer also helps analyze and present acquired data.

Graphics Video Terminals: Three DEC VT-240 monochrome graphics video terminals present antenna patterns for inspection or confirmation prior to hardcopy plotting.

Antenna Pattern Recorders: *Two Scientific-Atlanta 1581 antenna pattern recorders* provide the capability to generate analog patterns while operating the ranges in manual mode. A Hewlett-Packard 7550A pen plotter is the normal hardcopy pattern output device when operating the ranges in automatic mode.

Dot-Matrix Line Printer: A DEC LXY-22 600-line per minute dot-matrix line printer produces hardcopy tabulations of acquired data, calibration and gain files, results of data analyses, and various other required listings.

RF Power Meter: A Hewlett-Packard 438A two-channel digital power meter, in conjunction with the Hewlett-Packard 8480 series power sensors, provides precision power measurement capability over the frequency range of 10 MHz to 50 GHz. The power meter is not essential to the operation of the system, but it can be a valuable diagnostic tool when used to confirm signal levels at important points in the RF signal path.

2.3 COMPARISON OF CAPABILITIES

a. General. Because the two ranges have the ADAAS and support crew in common, the test officer is spared many of the details associated with tailoring a test to one range or the other. However, it is important for the test officer to understand the ranges' disparate capabilities in order to plan an effective and efficient test. Some tests will fall into the gray area where the ranges' capabilities overlap. The test officer can then base his decision on cost, availability, timeliness or other criterion.

b. Decision Flowchart. Figure 2 is a flowchart that summarizes the process a test officer should use to decide which facility to use for a particular test. In doing so, it provides a concise comparison of the two facilities. The decision process hinges primarily on the following key characteristics of the ranges:

	Arc Range	Compact Range
Frequency Range:	20 MHz to 18 GHz	6 GHz to 40 GHz
Weight Capacity:	60 tons	70 tons
Accuracy Limitations:	Near-field limits	Reflector tolerance, scatter

(1) The first two parameters are fairly straightforward; the weight of the test vehicle and the frequency range of its antenna either fall into one range, the other, both, or neither. The accuracy limitations are a more subtle issue. Appendix C discusses the limitations imposed by the near-field nature of a range such as the Arc Range. Essentially, at near-field distances accuracy suffers because of phase errors caused by the curved wavefront of test signals arriving at the antenna under test. The higher the frequency, the more pronounced the effect. For many types of measurements, for instance determining whether a particular antenna exhibits nulls in its radiation pattern, some near-field error can be acceptable.

(2) The Compact Range avoids this problem by collimating the test signal, simulating a near-infinite distance between the signal source and the antenna under test. This occurs within a 50-foot-diameter area centered on the positioner called the quiet zone. Disturbances in the phase of the arriving signals can result from irregularities in the shape of the reflector, or from stray signals reflected by the ground and reflector supports. At high frequencies especially, these disturbances are considerably less than the near-field phase error would be. This generally makes the Compact Range the facility of choice for frequencies that fall within both ranges' capabilities (6 to 18 GHz).

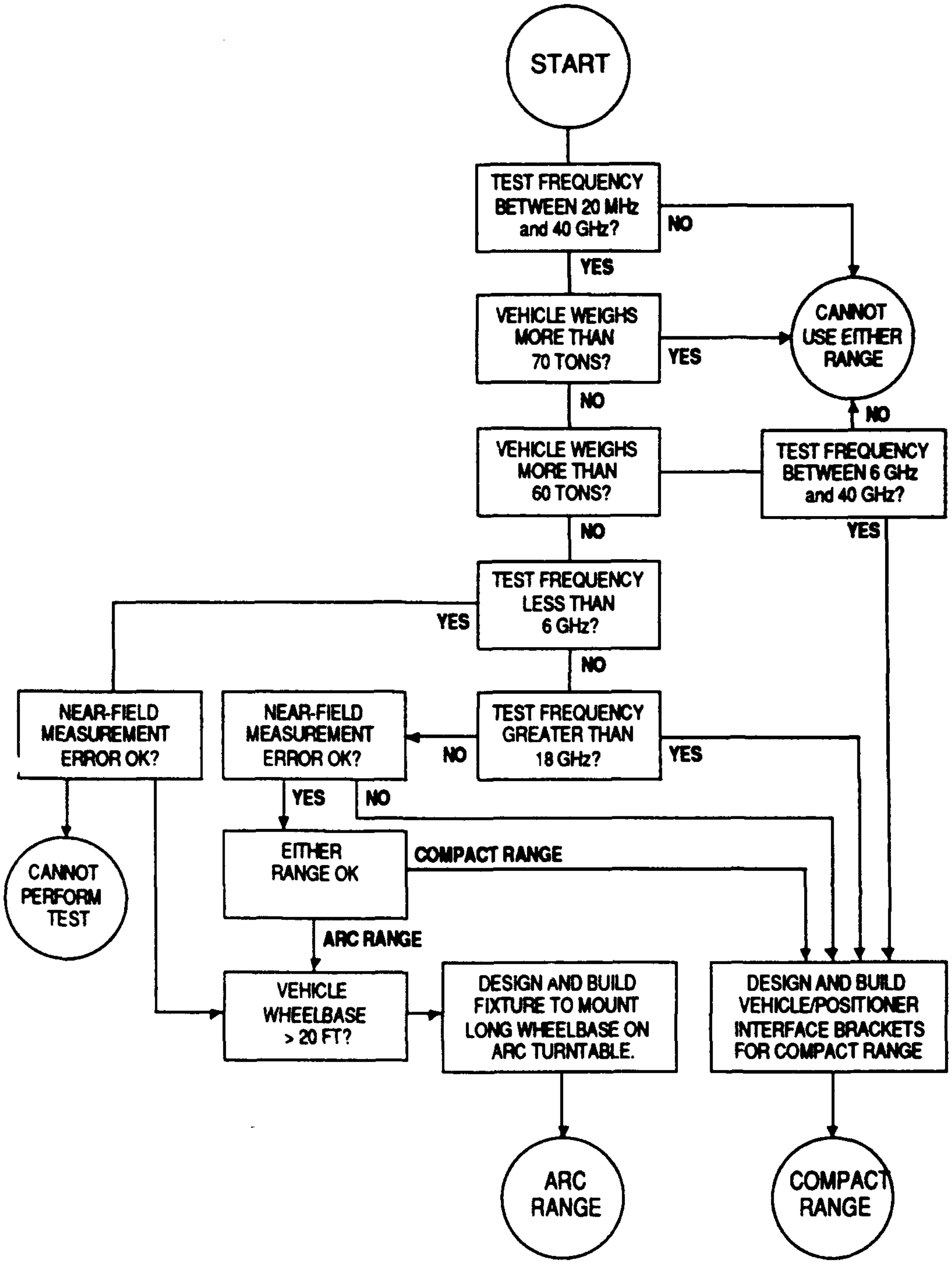

Figure 2. Decision flowchart.

3. PREPARATION FOR TEST

a. Activate a project notebook to record all pertinent technical information.

b. Prepare a checklist using appendix A as a guide.

c. Provide security precautions when required.

d. Prepare and review detailed test objectives, criteria, and plan. Verify that test specifications are within range capabilities.

e. Schedule and coordinate the availability of the test item and range.

f. Ensure that all test personnel are familiar with the required technical and operational characteristics of the test item.

g. Inspect the test item for an: defects that may affect system performance.

h. Prepare adequate safety precautions and ensure that all safety procedures are observed throughout the test.

i. Verify proper operation of all test equipment in the ADAAS system. All calibration stickers should be current.

4. TEST CONTROLS

a. Maintain constant temperature within $\pm$ 5° F for all trailer-housed instrumentation throughout the test.

b. Allow sufficient warm-up time for all equipment according to the manufacturer's recommendations.

c. Intermediate frequency (IF) calibration checks should be performed at periodic intervals. If desired, system software can perform these checks automatically at operator-specified intervals.

d. Perform daily pretest inspection of the test item, positioner system, and all range instrumentation for obvious problems.

5. PERFORMANCE TESTS

The test procedures that follow may be modified to satisfy the requirements of a particular test, provided that the test results can be proven to be valid. These procedures should be applicable as presented below for the majority of tests performed on the Arc and Compact Ranges.

5.1 ANTENNA RADIATION PATTERN MEASUREMENTS

a. The primary function of the Arc and Compact Ranges is antenna pattern measurement. Antenna patterns provide data on the radiation properties of antennas as a function of direction. Typically this is accomplished by sampling the amplitude and/or phase of the antenna's radiation at points on a sphere centered on the test antenna.

b. Antenna performance parameters determined through antenna pattern measurement include gain, main beam location, beamwidths, sidelobe levels and locations, null depths and locations, secondary beam peaks and locations, and multiple beam peaks and locations.

c. On the Arc Range, movement of the probe antenna on the arc from the horizon (0 degrees elevation) to zenith (90 degrees elevation), combined with 360-degree azimuth rotation of the turntable, permits sampling of the radiation for all points on the upper hemisphere. Antenna pattern measurement of the lower hemisphere is accomplished by inverting the test item.

d. Due to the finite separation between the probe and test antennas on the Arc Range, there are errors due to phase contributions associated with direct and reflected radiation paths from the test item. As the physical separation of the direct and reflected radiation paths increases, so do these errors, but for many systems these errors are acceptable. A more detailed discussion of these errors is included in appendix C.

e. On the Compact Range, hemispherical sampling of the antenna radiation is accomplished in a manner similar to that for the Arc Range. Movement of the turntable elevation axis from the horizon (0 degrees elevation) to zenith (90 degrees elevation), combined with 360-degree azimuth rotation of the turntable, permits sampling of the radiation for all points on the upper hemisphere. Antenna pattern measurement of the lower hemisphere is accomplished by inverting the test item.

f. Because the test item is illuminated by a collimated field of RF energy on the Compact Range, there are no errors due to phase contributions associated with direct and reflected radiation paths from the test item, as on the Arc Range. The primary limitation on the accuracy of antenna pattern measurement on the Compact Range is the quality of the collimated RF energy within the area described by the test item. This area should fall within the 50-foot diameter quiet zone of the range. The quiet zone is the area around the Compact Range turntable where the RF energy is perfectly collimated in amplitude and phase. The accuracy of the quiet zone amplitude and phase collimation is measured by probing the RF field within this zone.

5.1.1 Automated Antenna Pattern Measurements

5.1.1.1 Methods

Most antenna pattern measurements performed on the Arc and Compact Ranges can be done under the control of the automatic range control software. This relieves the operator of many routine measurement setup tasks.

a. On the Arc Range, position the test item so that the phase center of the test antenna is as near as possible to the center of measurement sphere, as defined by the radial center (or focal point) of the arc. If the location of the phase center of the test antenna is unknown, as is typically the case, a good estimate of its location is usually the geometric center of the antenna.

b. On the Compact Range, the test item must be mounted on the positioner platform with suitably designed brackets. The center of gravity of the test item should be placed as low as possible over the azimuth axis center of rotation.

c. Using the minicomputer's database menu, define the parameters of the test such as measurement frequencies, antenna polarization, and spatial sampling set (the azimuth and elevation intervals at which to measure the antenna's radiation).

d. Load the test parameters into the range control microcomputer.

e. Request that the range control microcomputer calibrate the instrumentation. This calibration procedure should not be confused with long-term maintenance calibrations that must be performed periodically. This system calibration procedure checks system linearity and dynamic range, and adjusts the IF stages if required.

f. This calibration corrects for short-term temperature drifts in the system and should be repeated periodically during data acquisition. The recommended re-calibration interval is 30 minutes, but longer or shorter intervals may be selected based on individual test requirements.

g. The range control microcomputer will either perform this calibration automatically or recommend the calibration at regular intervals as specified by the operator. If "recommendations only" are specified by the operator, it is up to the operator to initiate calibration according to the software recommendations. In either case the actual calibration procedure is performed via automatic software routines.

h. Initiate data acquisition through the range control microcomputer menu. All data collected are automatically stored for analysis and presentation.

5.1.1.2 Data Required

When an automatic antenna pattern measurement is performed, the data collected are stored along with the test parameters in the database minicomputer. Analysis and presentation of these data are described in paragraph 6.

5.1.2 Manual Antenna Pattern Measurements

5.1.2.1 Methods

Throughout this description it is assumed that the receiver is operating properly so that the measured amplitude varies linearly with input power level. If the input level is too great, the receiver can become saturated and measurement response can become non-linear. If the input level is too low, noise can mask the desired signal response. Refer to the receiver operating manual for direction regarding the appropriate range of input signal levels. Use a calibrated attenuator to verify linear response over this input signal range.

a. Configure the antenna pattern measurement instrumentation as shown in figure 3 for the Arc Range, and as shown in figure 4 for the Compact Range. Normally this configuration is identical to the automatic antenna measurement system except that the instrumentation is under manual control.

b. Perform the desired "cuts" through the antenna radiation pattern by positioning one axis to the desired angle and then scanning the other axis through the desired range of angles. The chart axis of the antenna pattern recorder should correspond to the angular movement of the positioner. The pen axis will then correspond to the amplitude output of the receiver. This configuration will produce graphs of amplitude versus angle for each desired cut through the pattern.

5.1.2.2 Data Required

Each pattern recording should be labeled carefully to identify the antenna, measurement frequency, stationary axis position, angular scale (and offset, if applicable) of moving axis, amplitude scale (and offset, if applicable), and any other special comments. The required patterns should be checked off the test plan as they are completed in order to ensure that all required patterns are measured.

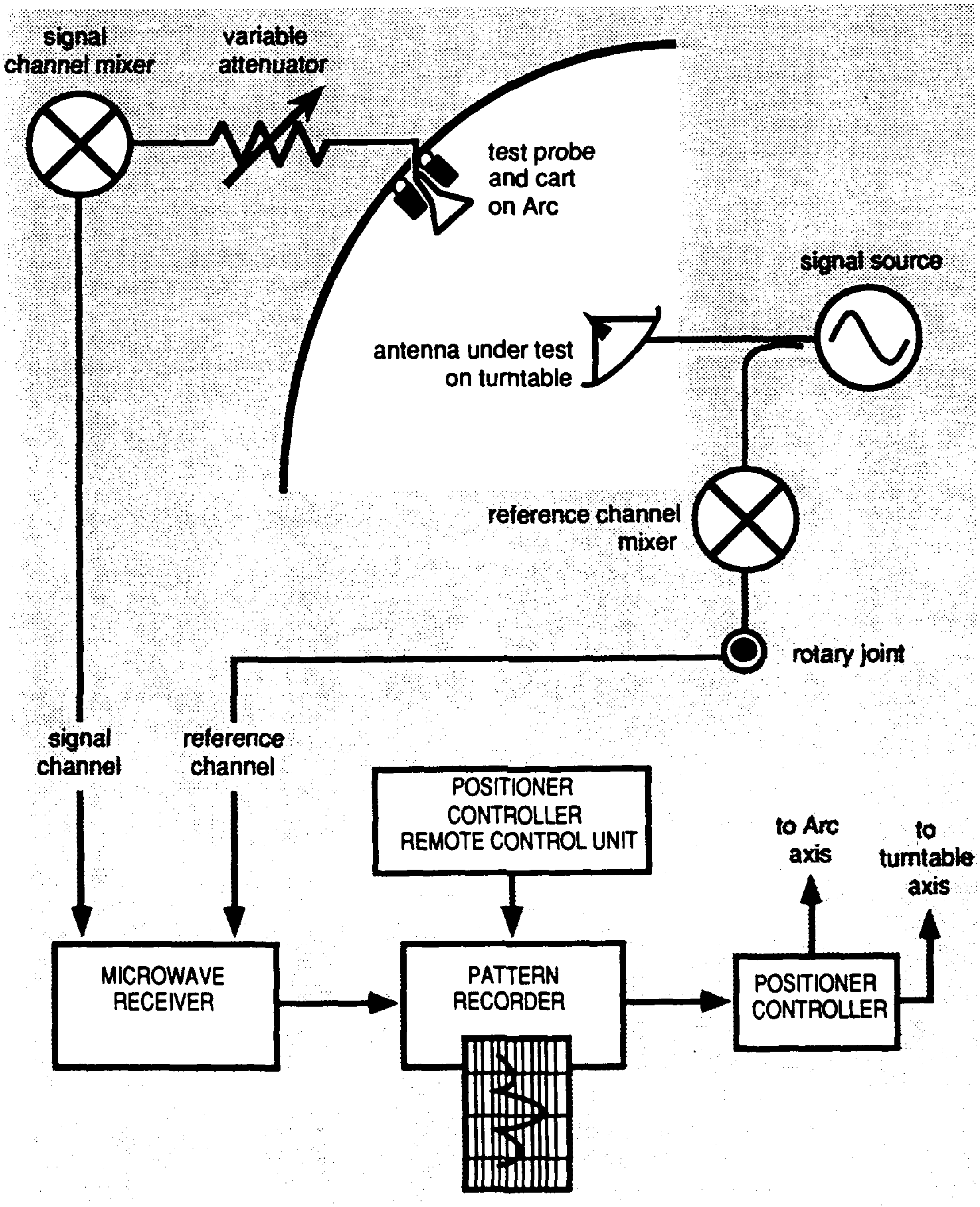

Figure 3. Arc Range manual antenna pattern measurement system.

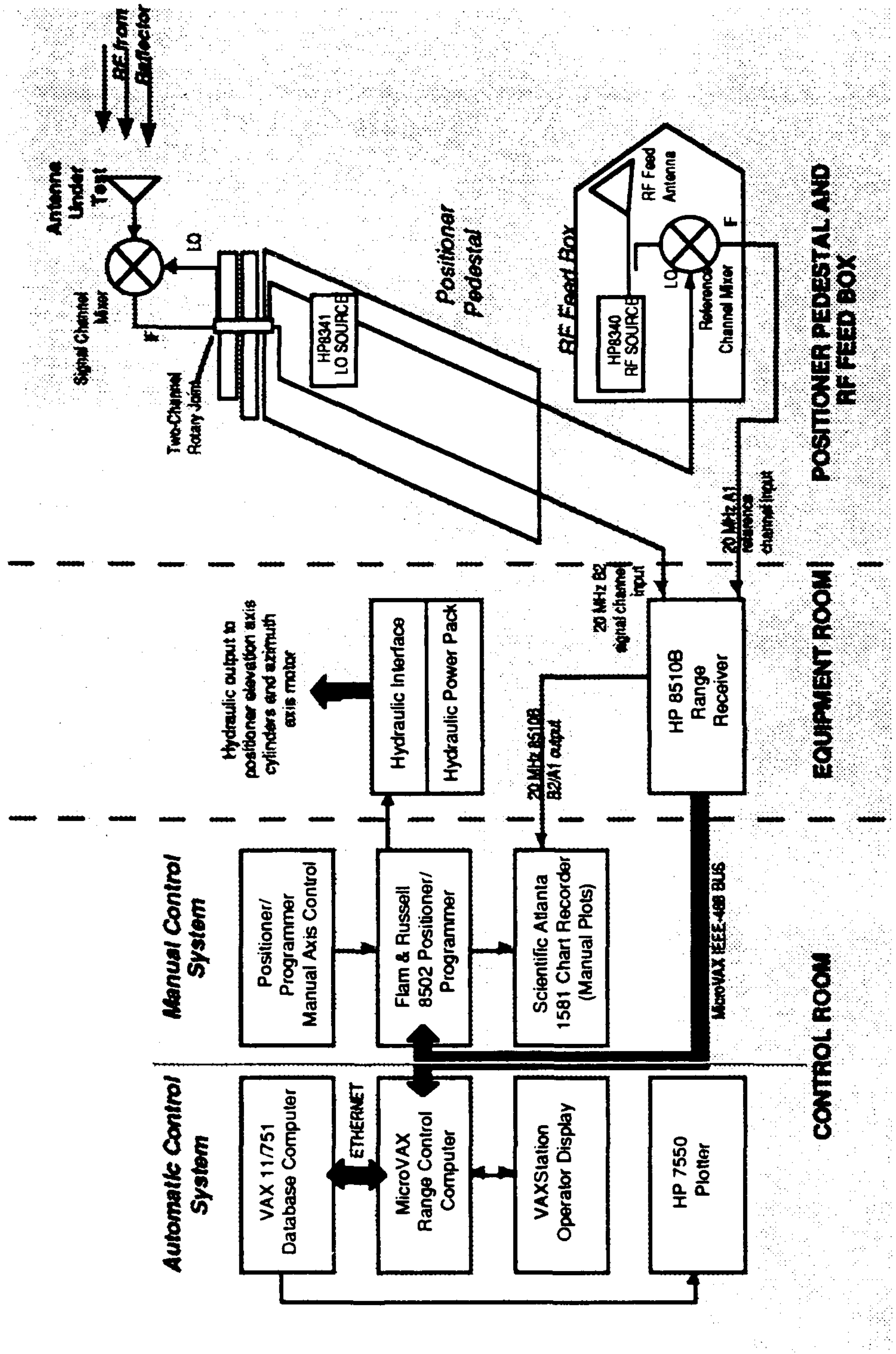

Figure 4. Compact range manual antenna pattern measurement system.

5.2 ANTENNA GAIN MEASUREMENTS

a. Antenna gain is a measure of the strength of an antenna's radiation in a particular direction as compared to an antenna that radiates with equal strength in all directions (i.e., isotropically). According to the ANSI/IEEE Standard 100-1984, "IEEE Standard Dictionary of Electrical and Electronic Terms," antenna gain is strictly defined as the "ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically." If the direction is not explicitly stated, it is understood to be the direction of maximum radiation strength (i.e., the peak of the main beam).

b. It is important to note that the definition of gain does not involve polarization or impedance mismatch losses, but it does include dissipative losses. This is implied by the use of the word "accepted" in the definition above.

c. Because no real antenna radiates isotropically, it is more feasible to measure an antenna's gain by comparing it to another antenna whose gain relative to isotropic has been computed by its geometry, or measured by a complicated three-antenna technique. These antennas are called standard gain antennas. In the microwave frequency region these standard gain antennas typically take the form of a pyramidal horn and are called standard gain horns. Each standard gain horn has associated with it a graph of gain versus frequency.

d. The technique of measuring the gain of an antenna by comparison to another antenna of known gain is known as the gain comparison method, or more commonly, the gain transfer measurement method.

5.2.1 Automated Antenna Gain Measurements

The gain transfer technique is used in the case of automated gain measurements. Because of the need to replace the test antenna with a standard gain antenna, the process of gain measurement is not completely automated. The computer system will do the following automatically: recommend standard gain horns to use, compute an optimal reconnection sequence to minimize operator intervention, compute the test antenna's gain at each measurement frequency, and handle all record keeping tasks.

5.2.1.1 Methods

A gain measurement can be performed any time after a test definition has been loaded into the range control microcomputer, and before that test has been completed. The recommended time is immediately after loading the test definition. If a major problem exists with the test antenna, its interconnections with the instrumentation, or with the instrumentation itself, a gain measurement may reveal the problem and save valuable test time.

a. At any convenient time during a test, select a gain measurement on the range control microcomputer menu.

b. Select the antennas, frequencies, and standard gain horns to be used for this set of gain measurements (all gain measurements do not have to be performed at the same time). Note that if the operator wishes to use a standard gain horn for which the computer has no data, he will need to enter the absolute gain at the test frequency and the nominal beamwidths for the main beam peak search algorithm.

c. Connect each standard gain horn to its corresponding RF output as directed by the computer. As each gain is measured, the results are indicated on the range control microcomputer terminal.

5.2.1.2 Data Required

When automated gain measurements are requested, the computer stores the name of the standard gain horn used and the measured gain of the test antenna at each frequency. The data are presented on the range control microcomputer terminal as the measurements are completed, and also during analysis as described in paragraph 6.

5.2.2 Manual Antenna Gain Measurements

If for some reason automatic antenna gain measurement is inappropriate, unavailable, or invalid for a given test, manual gain measurements can be performed.

5.2.2.1 Methods

a. Configure the antenna pattern measurement instrumentation as shown in figure 3 for the Arc Range, and as shown in figure 4 for the Compact Range.

b. Substitute an antenna of known gain (i.e., a standard gain horn) for the test antenna.

c. Locate the direction of maximum received power (the location of the main beam peak) and adjust attenuations and offsets for a convenient reference amplitude. It is important for the standard gain antenna to be at the same location as the test antenna when this is done.

d. Replace the standard gain antenna with the test antenna.

e. Again locate the direction of maximum received power and measure the difference in amplitude between this level and the level set for the standard gain antenna. If the receiver is operating in a non-linear or excessively noisy region of input power level, attenuation may be added or removed to bring the receiver back into its region of linear response.

f. The absolute gain of the test antenna (in dBi) is equal to the gain of the standard gain horn (in dBi) plus the measured gain difference (in dB) plus any attenuation (in dB) that may have been added (subtract any attenuation that may have been removed).

5.2.2.2 Data Required

Use the antenna gain data collection form in appendix B to record the gain difference, standard gain horn nomenclature and gain, and gain of test antenna for each frequency and antenna for which the gain measurement is taken.

5.2.3 Weather Effects on Antenna Gain Measurements

a. Precipitation can significantly attenuate radio waves in the millimeter-wave portion of the electromagnetic spectrum. The degree of attenuation is a complicated function of radiated wavelength and precipitation size, state (frozen or unfrozen), and rate. Attenuation due to both scattering and absorption increases rapidly with increasing precipitation rate and may affect test data during periods of heavy precipitation. Consider this effect when testing in the 10- to 40-GHz frequency band in precipitation.

b. Meteorological support during antenna pattern measurements may be requested from the respective meteorological support team.

6. DATA REDUCTION, PRESENTATION, AND ANALYSES

6.1 REDUCTION

a. Reduction of data collected on the ATF antenna ranges is limited primarily to the determination of the following antenna performance parameters:

(1) Gain.

(2) Main beam location.

(3) Beamwidths.

(4) Sidelobe levels and locations.

(5) Null depths and locations.

(6) Secondary peaks.

(7) Multiple beams.

b. Further data reduction can be performed to examine the behavior of the above parameters with respect to frequency, configuration, or whatever variables may be relevant to a particular test.

c. Data reduction can be performed either manually or by the database minicomputer. The parameters listed above are currently available through automatic pattern analysis programs. Any additional data reduction can be performed manually.

6.2 PRESENTATION

a. Antenna pattern measurement data is usually provided in the form of graphical presentations of the antenna patterns, tables of the performance parameters listed in paragraph 6.1, and occasionally by tabular listings of raw data.

b. If the antenna pattern data are collected by the automatic system, presentations can be requested as outputs to the plotter, printer, and/or graphics terminals. If the data are collected manually, the data will already be in the form of an antenna pattern, and tables of antenna performance parameters can be manually generated.

c. Antenna Pattern Plots. Antenna pattern plots are graphical presentations of the radiation properties of antennas as a function of direction. The most common formats for antenna pattern plots are rectangular, polar, and three-dimensional.

6.2.1 Rectangular Antenna Pattern Plots

Rectangular antenna pattern plots are generated using an orthogonal coordinate system. The abscissa (y-axis) represents the relative amplitude of the antenna radiation in decibels and the ordinate (x-axis) represents the azimuth or elevation axis angle. The pattern is a presentation of a cut through one axis of the antenna while the other axis is held stationary. Labelling of the stationary axis position as well as the ordinate and abscissa axes is performed automatically on computer generated patterns. Because the ordinate axis can be easily scaled to whatever angular range is desired, the rectangular format antenna pattern is probably the most popular. Figure 5 is an example of a rectangular antenna pattern plot.

6.2.2 Polar Antenna Pattern Plots

Polar antenna pattern plots are generated using a polar coordinate system. The radial axis represents the relative amplitude of the antenna radiation in decibels and the polar angle represents the azimuth or elevation axis angle. The pattern is a presentation of a cut through one axis of the antenna while the other axis is held stationary. Labelling of the stationary axis position is performed automatically on computer generated patterns. The polar axis scale is always a full 360 degrees and is not well suited to narrow beamwidth antennas. However, polar plots provide a visually realistic presentation of the radiation pattern and are very popular for wide beamwidth antennas. Figure 6 is an example of a polar antenna pattern plot.

6.2.3 Three-Dimensional Antenna Pattern Plots

A three-dimensional antenna pattern plot represents a two-dimensional projection of a set of antenna patterns. The result is similar to an architectural perspective drawing where lines that would normally be hidden behind another part of the surface are suppressed for clarity. It is difficult to quantitatively evaluate an antenna's performance using a three-dimensional plot, however, this presentation is very effective for qualitative evaluations. Figure 7 is an example of a three-dimensional antenna pattern plot.

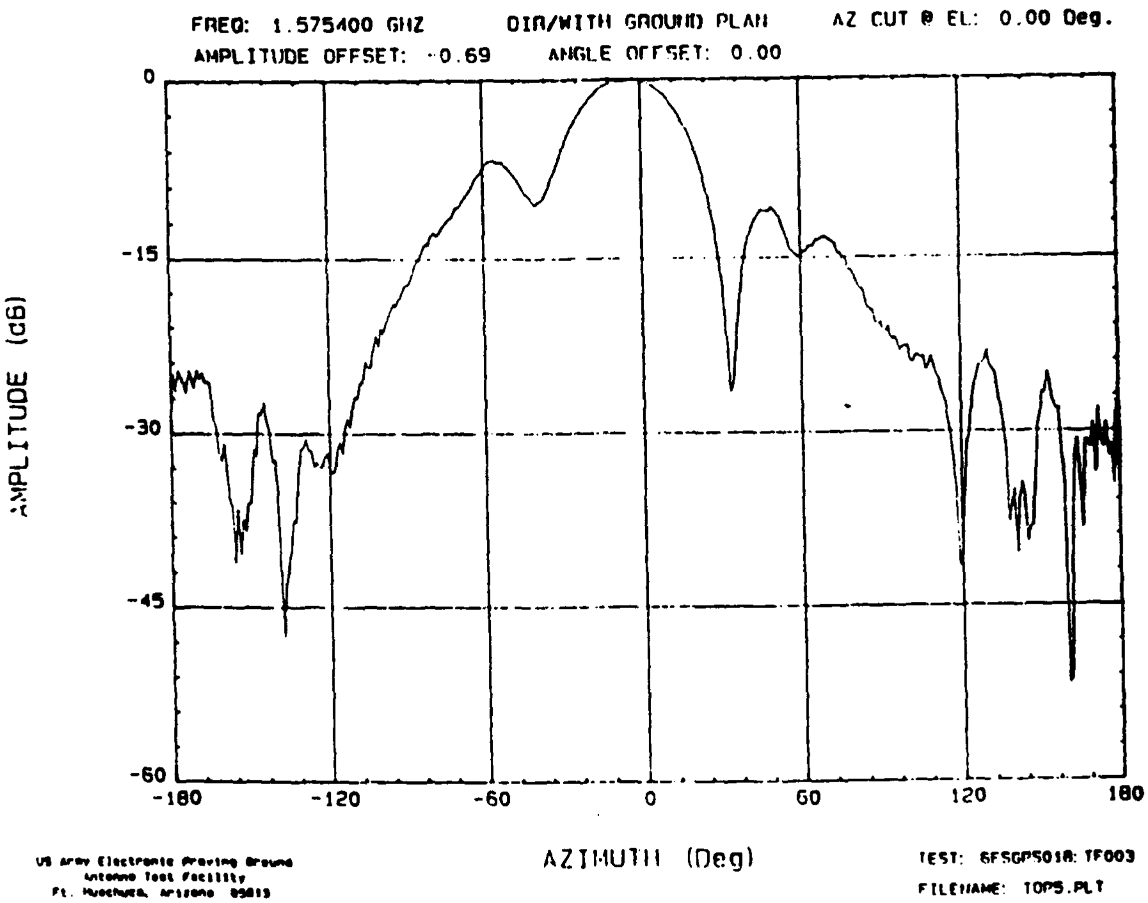

Figure 5. Example of a rectangular antenna pattern plot.

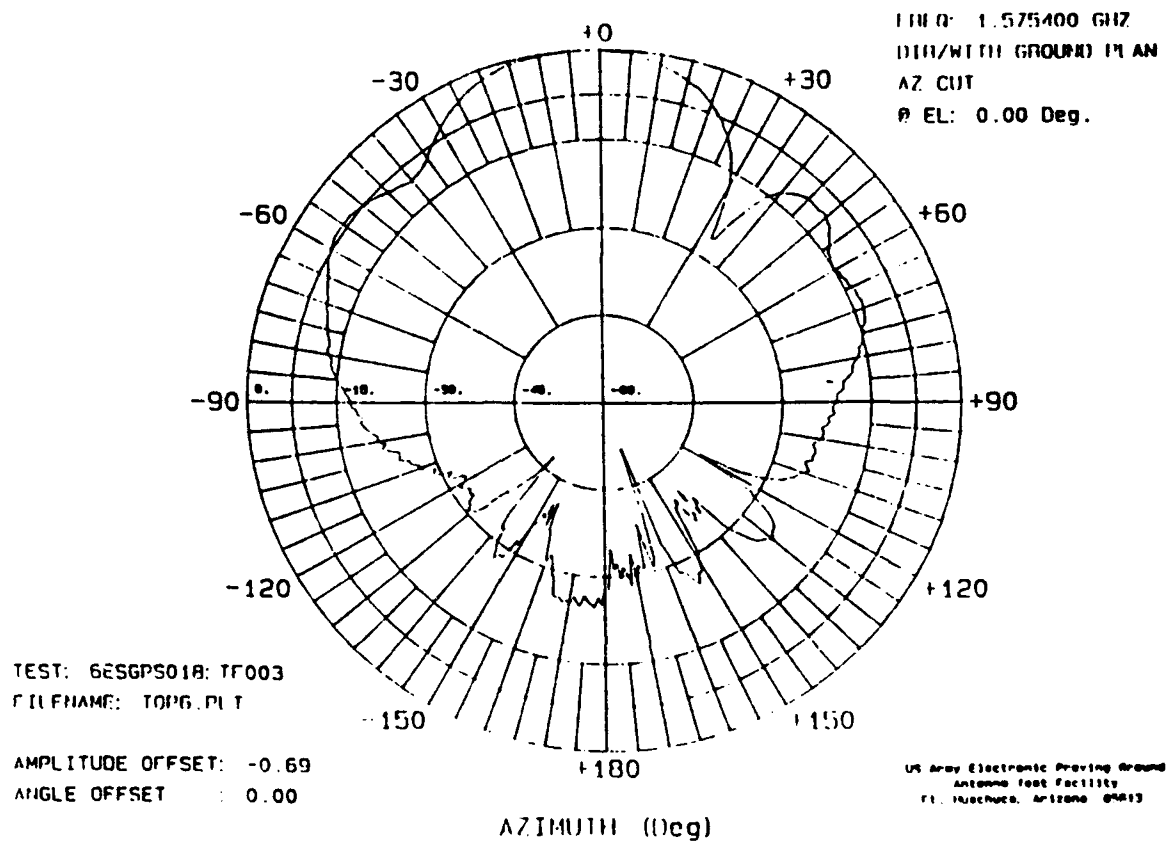

Figure 6. Example of a polar antenna pattern plot.

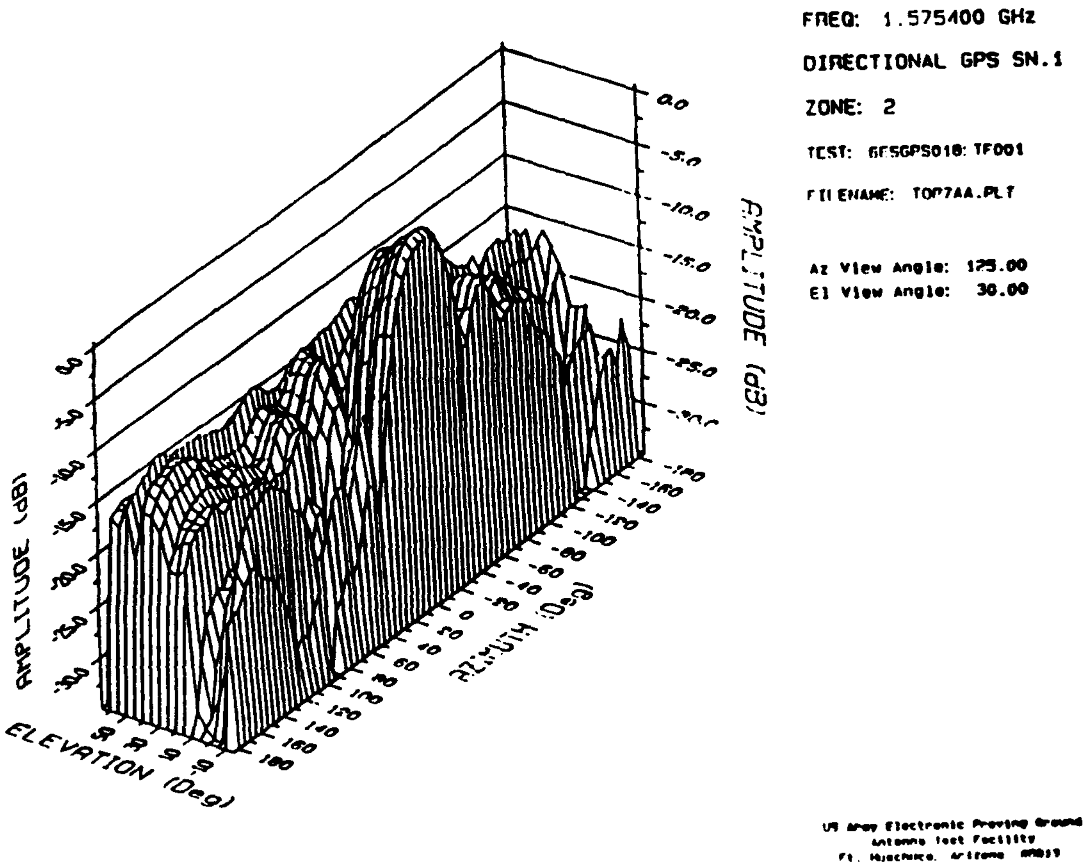

Figure 7. Example of a 3-D antenna pattern plot.

6.3 ANALYSES

6.3.1 Gain

a. The gain transfer method of gain measurement (see description in paragraph 5.2) is recommended because of its simplicity. All that is required is to measure the difference between the gain of the test antenna and standard antenna of known gain at the test frequency. This difference is then added to the known gain of the standard antenna to determine the absolute gain of the test antenna.

b. If gain measurements are performed under automated computer control, the microcomputer will look up the gain data file for the standard antenna in use and perform the computations automatically.

c. If gain measurements are performed under manual control, the gain of the standard antenna must be determined from the gain-versus-frequency curves supplied with the standard antenna, and the absolute gain calculations performed manually.

6.3.2 Main Beam Location

a. Main beam location is the azimuth and elevation angle where maximum radiation of the test antenna occurs. These angles are always given relative to some reference position (i.e., the horizon directly ahead of the vehicle).

b. If the antenna pattern data are collected by the automatic system, the main beam location is determined by a search performed during calibration for the test and stored for presentation in the analysis report. If the antenna patterns are collected manually, the beam location chart in Appendix B can be used to tabulate these values.

6.3.3 Beamwidths

a. The half-power (3-dB) azimuth or elevation beamwidth of an antenna is defined as the angular separation between the two points on either side of the main beam which lie 3 dB below the peak in the specified plane. Null-to-null, 1/4-dB and 10-dB beamwidths may also be of interest for a particular test.

b. If the antenna pattern data are collected by the automatic system, the azimuth and elevation beamwidths are calculated by the minicomputer in response to an analysis request. If the antenna patterns are collected manually, the beamwidth chart in appendix B can be used to tabulate these values.

6.3.4 Sidelobe Levels and Locations

a. The levels and locations of sidelobe peaks are usually of interest to the antenna engineer. Typically the first sidelobe on either side of the main beam and the highest sidelobe are of special interest. These levels are usually measured relative to the peak of the main beam.

b. If the antenna pattern data are collected by the automatic system, the sidelobe levels and locations are calculated by the minicomputer in response to an analysis request. Quadratic interpolation of the data utilizing non-linear regression analysis is used to enhance the accuracy of these computations. This method fits a quadratic curve to the data points of the antenna pattern and yields more accurate interpolation of the data than linear regression techniques. If the antenna patterns are collected manually, the sidelobe level and location chart in appendix B can be used to tabulate these values.

6.3.5 Null Depths and Locations

a. The levels and locations of null depths are usually of interest to the antenna engineer. Typically the first null on either side of the main beam is of special interest. These null levels are usually measured relative to the peak of the main beam.

b. If the antenna pattern data are collected by the automatic system, the null levels and locations are calculated by the minicomputer in response to an analysis request. If the antenna patterns are collected manually, the beamwidth chart in appendix B can be used to tabulate these values.

6.3.6 Secondary Peaks

a. If the antenna has multiple peaks on the main beam, it may be important to know where each secondary peak occurs and at what level.

b. If the antenna pattern data are collected by the automatic system, the secondary peak levels and locations are calculated by the minicomputer in response to an analysis request. Quadratic interpolation methods as described in 6.3.4b above are used to enhance the accuracy of these computations. If the antenna patterns are collected manually, the beam location chart in Appendix B can be used to tabulate these values.

6.3.7 Multiple Beams

a. Some antenna patterns exhibit multiple beams. The levels and locations of these multiple beams are usually of interest to the antenna engineer.

b. If the antenna pattern data are collected by the automatic system, the multiple peak levels and locations are calculated by the minicomputer in response to an analysis request. Quadratic interpolation methods as described in 6.3.4b above are used to enhance the accuracy of these computations. If the antenna patterns are collected manually, the beam location chart in appendix B can be used to tabulate these values.

APPENDIX A. ANTENNA TEST CHECKLIST

1. Initial Preparation

- Determine critical test objectives ☐
- Acquire applicable documentation on test item and proposed range ☐
- Acquire authorization to perform tests ☐
- Acquire applicable military standards if necessary ☐
- Determine security classication of test item ☐

2. Assessment of Test Range Requirements

- Verify that specifications of range satisfy test requirements ☐
- Verify that security requirements can be satisfied ☐
- Verify adequate frequency coverage ☐
- Determine if expected dynamic range is sufficient ☐
- Verify compatibility of probe antenna polarization ☐

3. Test Logistics

- Schedule availability of test item ☐
- Schedule availability of range ☐
- Schedule availability of support personnel ☐
- Schedule availability of airframe if necessary ☐
- Schedule availability of test item support cribbing if necessary ☐
- Prepare any special power requirements if necessary ☐
- Identify and obtain non-standard instrumentation if necessary ☐
- Confirm availability of required gain standards ☐
- Negotiate test responsibilities among participants ☐
- Coordinate security guidelines and support ☐
- Verify that proper safety precautions are instituted ☐

4. Test Requirements and Data Collection

- Activate project notebook and assign test officer to maintain it ☐
- Prepare detailed test plan:
  - *Specifiy frequencies* ☐
  - *Prepare pattern checklist* ☐
  - *Specify gain measurements* ☐
- Distribute test plan and brief all participants ☐
- Provide photographic documentation of test if required ☐
- Complete test plan ☐

5. Reporting

- Determine security classification of material and coordinate security guidelines ☐
- Specify and perform data reduction (beamwidths, sidelobes, etc.) ☐
- Identify proper report format ☐
- Write report ☐
- Distribute report ☐

APPENDIX B. ANTENNA TEST DATA SHEETS

BEAM LOCATION

Antenna: ______________________________

Date: ______________________________

Engineer: ______________________________

FREQUENCY (GHz)	AZIMUTH						ELEVATION					
	MAIN BEAM PEAKS			SECONDARY BEAMS			MAIN BEAM PEAKS			SECONDARY BEAMS		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd

BEAMWIDTHS

Antenna: ______________________________

Date: ______________________________

Engineer: ______________________________

FREQUENCY (GHz)	**AZIMUTH** (degrees)			**ELEVATION** (degrees)		
	3 dB	10 dB	NULL-TO-NULL	3 dB	10 dB	NULL-TO-NULL

SIDELOBE LEVELS AND LOCATIONS

Antenna: ______________________ *Cut: ______________________

Date: ______________________

Engineer: ______________________

FREQUENCY (GHz)	RIGHT SIDELOBE		LEFT SIDELOBE		HIGHEST SIDELOBE	
	LOCATION (degrees)	LEVEL (dB from peak)	LOCATION (degrees)	LEVEL (dB from peak)	LOCATION (degrees)	LEVEL (dB from peak)

*Azimuth or elevation

ANTENNA GAIN

Antenna: ______________________

Date: ______________________

Engineer: ______________________

FREQUENCY (GHz)	STANDARD GAIN ANTENNA NAME	GAIN		
		STANDARD GAIN ANTENNA (dBi)	DIFFERENCE (dB)	ANTENNA UNDER TEST (dBi)

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APPENDIX C. ERRORS DUE TO FINITE RANGE LENGTH

The phase of an electromagnetic wave has a profound effect on how it combines with another electromagnetic wave. For example, if two waves are of equal amplitude and are in phase, they add constructively to produce a wave of twice the amplitude of each of the original waves. If the same equal-amplitude waves are 180 degrees out of phase, they cancel each other out completely. Figure C-1 illustrates these effects. An infinite number of combinations exist between these extremes.

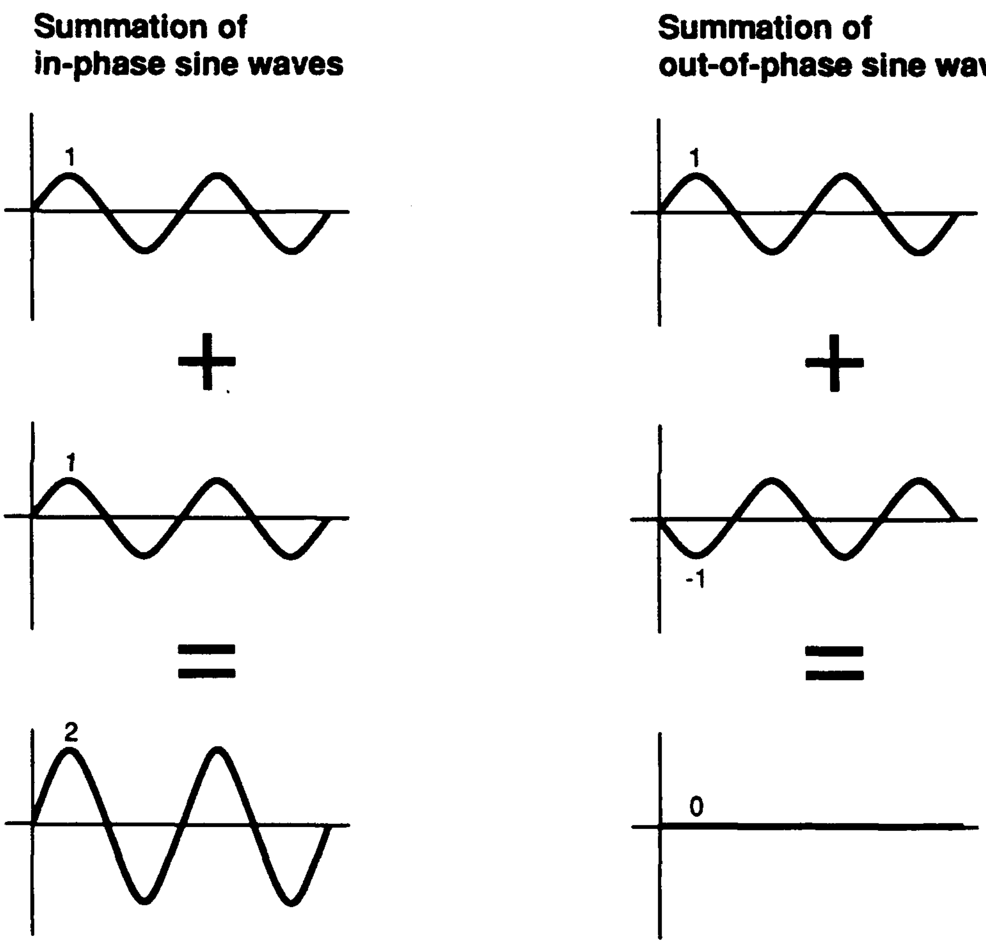

Figure C-1. Waves in phase add constructively; out-of-phase waves cancel one another.

An antenna's radiation pattern is determined by how the electromagnetic waves coming from the different parts of the antenna combine at the measurement point. As demonstrated above, the way these various contributions sum at the measurement point is affected greatly by their relative phases.

Because the phase of an electromagnetic wave depends on the length of the path over which it has traveled (and its initial phase) it is each to demonstrate that an antenna pattern will depend to some extent on the distance between the antenna under test and the probe antenna.

To understand this, consider the two contributions shown from the antenna in figure C-2 where the probe antenna is infinitely far away (left) compared to the case in which the probe antenna is closer to the antenna under test (right). Note the difference in path lengths for two arbitrary points on the test antenna. With the probe at infinity, the difference in path lengths is greater than when the probe is close. This means that, given the same initial phases, the contributions from these two points on the antenna under test will sum in a different way, depending on the separation between the probe and the antenna under test.

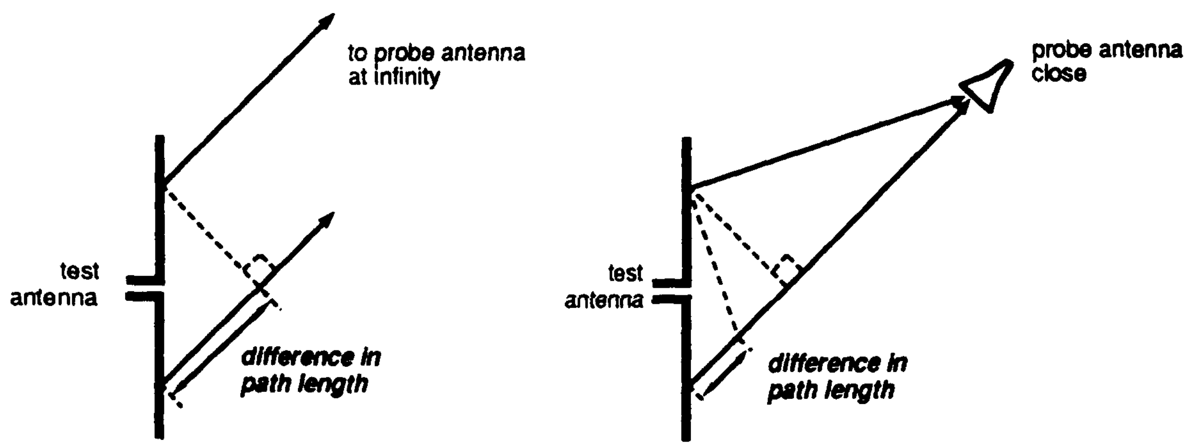

Figure C-2. Differences in path length with probe at infinity (left) and with probe close to test antenna (right).

This phenomenon will occur for contributions from all points on the antenna under test and all measurement points on a circular arc centered on the antenna under test. This is the reason the shape of an antenna pattern varies with range distance.

The usual effect of insufficient range separation between the test antenna and the probe is an apparent broadening of the main beam, elevation of sidelobe levels, merging of sidelobes into the main beam, and reduction in apparent directivity. The sidelobe effects are usually more pronounced in very low sidelobe antennas.

How much separation between the test antenna and the probe is required in order to make usable measurements of the antenna's pattern? That depends on two factors: the aperture of the antenna and the wavelength on which it will operate. A good rule of thumb for determining sufficient separation is:

$$R = 2D^2/\lambda$$

where: R is the range separation or range length
D is the maximum aperture dimension of the test antenna
l is the wavelength

This range criterion is based on the arbitrary choice of 22.5 degrees maximum quadratic phase error at the measurement plane. "Quadratic phase error" refers to the phase error due to the spherical nature of the phase fronts as they intersect a planar aperture as shown in figure C-3.

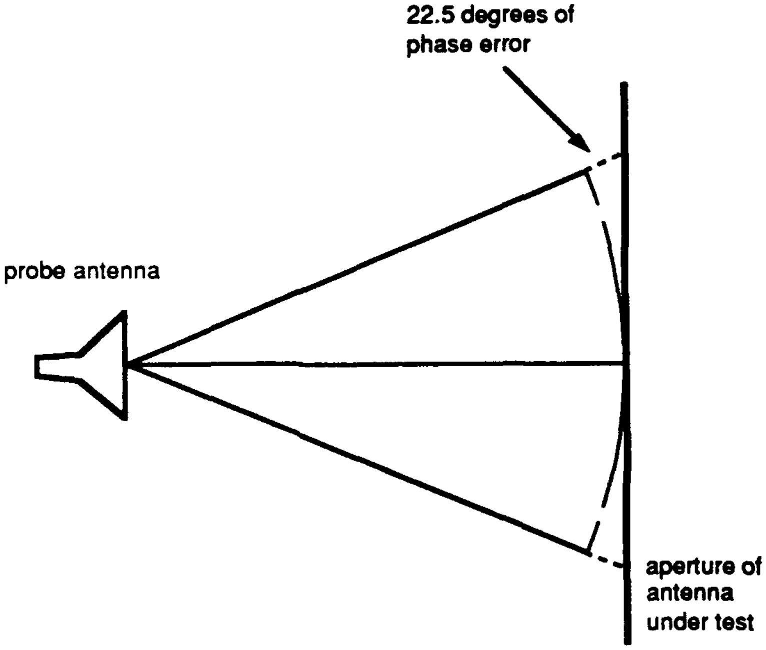

Figure C-3. Quadratic phase error of 22.5 degrees.

If the $R = 2D^2/\lambda$ criterion is applied to the Arc range with its 75-foot range length, and the largest dimension of the vehicle on which the antenna under test is mounted is taken as D, the range can be considered invalid for all but very large wavelengths (very low frequencies). For example, if an antenna is mounted on a vehicle 30 feet long, D is thus 30 feet, and the highest frequency that satisfies the $R = 2D^2/\lambda$ criterion is about 40 MHz.

The application of the $R = 2D^2/\lambda$ criterion may not be valid for many tests, however. Remember that the $R = 2D^2/\lambda$ criterion is the result of the totally arbitrary 22.5-degree maximum quadratic phase error requirement. This 22.5-degree phase error may be much more than sufficient for antennas with broad main beams and high sidelobes, but insufficient for narrow-beamed, low-sidelobe antennas. But in the case of the antenna with low sidelobes and a narrow beam, the vehicle on which the antenna is mounted is usually illuminated only by these low

sidelobes and should not affect the pattern much anyway. In such a case it may be more realistic to take D as the largest dimension of the antenna itself. This argument typically leads to satisfaction of the $R = 2D^2/\lambda$ criterion at much higher frequencies.

On the other hand, patterns of broad-beamed antennas such as dipoles, which may strongly illuminate the vehicle, are less affected by larger phase errors, and again the measurements may be valid at higher frequencies than those satisfying the $R = 2D^2/\lambda$ criterion. Some additional relaxation of this criterion may also be tolerable for tests where the utmost accuracy is not necessary and only larger changes in the antenna pattern are of concern.

In order to investigate these effects, a very simple model of the Arc range was simulated on a computer. It must be emphasized that this simulation represents a very simplified view of the Arc range. While it demonstrates that, for some cases, taking the maximum vehicle dimension as D is too conservative, it does not imply that there are no cases where the maximum vehicle dimension is a reasonable value for D.

In other words, each test item must be considered individually. If the accuracy required in a test cannot reasonably be expected on the Arc range, then either another test facility should be used (e.g., the Compact Range) or the accuracy requirements will have to be relaxed and the resulting inaccuracies handled accordingly.

The geometry shown in figure C-4 was used for the simulation. A colinear array of dipoles was used as the antenna so that both broad beamed antennas (e.g., a simple dipole) and relatively narrow-beamed antennas could be simulated with the same software. A flat plate was used to simulate the top surface of a vehicle on which the antenna was mounted. This flat plate acted like a mirror to create an image dipole array below it. The contributions of the actual dipoles and those of the image dipoles were summed at 900 points on a circular arc centered on the real dipole array to create simulated antenna patterns.

The analysis was carried out for two different radii for the circular measurement arc, one of 75 feet and the other of 7500 feet (to more closely approximate the infinite far field) for each antenna/ vehicle configuration shown in table C-I. The parameters were chosen to simulate a somewhat representative set of configurations.

Figures C-5 through C-20 are plots that represent the outcome of each computer-simulated test. The important thing to note about each figure is not how many ripples, nulls, or peaks appear in the patterns, but *the difference between the solid and dotted lines.* The difference between the two patterns represents the measurement error due to measuring at 75 feet (the solid line) and 7500 feet (the dotted line).

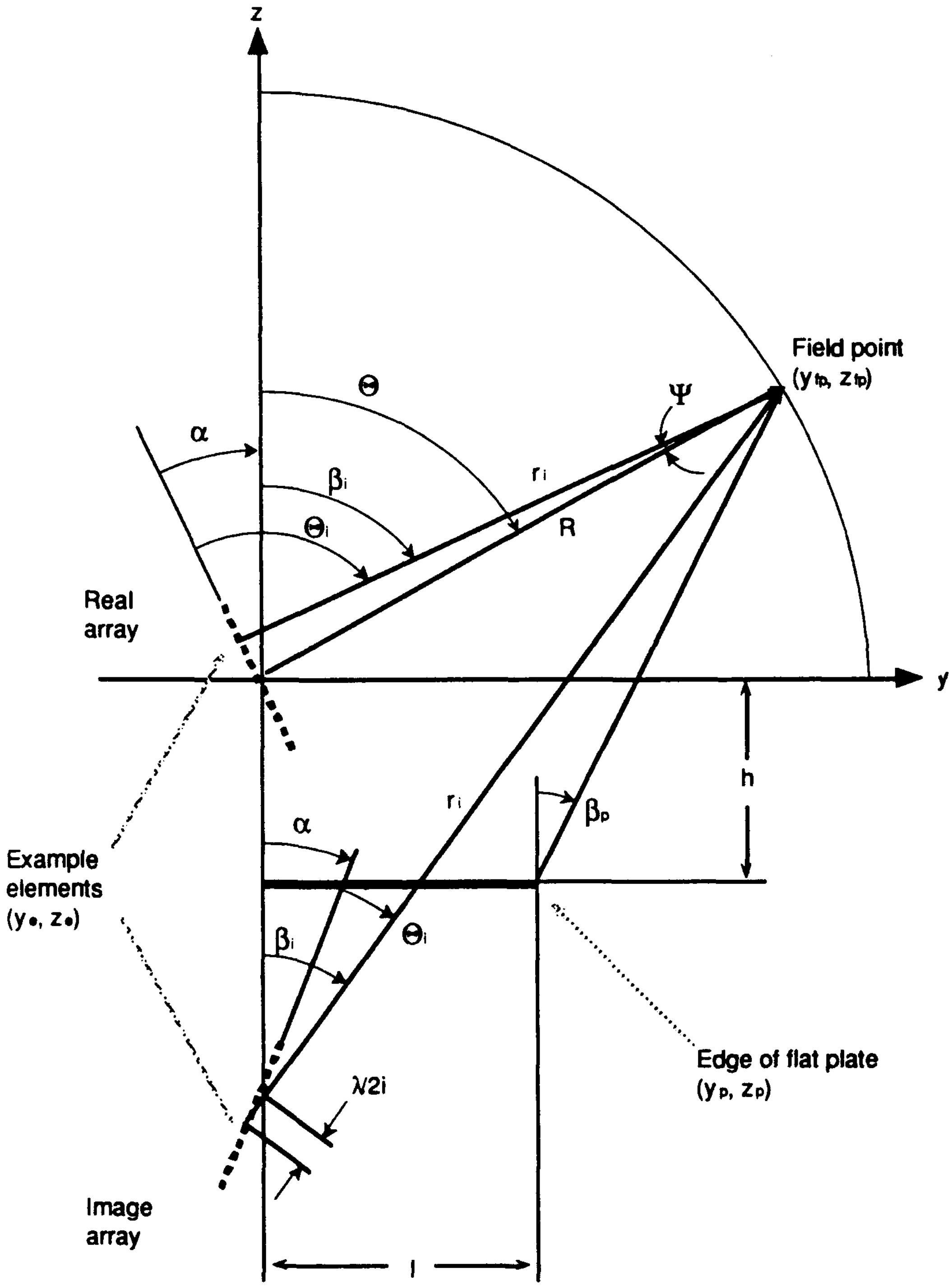

Figure C-4. Computer simulation geometry.

TABLE C-1. SIMULATED ANTENNA/VEHICLE CONFIGURATIONS

FIGURE	α (degrees)	NUMBER OF DIPOLES	HEIGHT ABOVE FLAT PLATE	*LENGTH OF FLAT PLATE
D-5	0	1	0.3 in.	2 ft
D-6	0	1	0.3 in.	10 ft
D-7	0	1	12 in.	2 ft
D-8	0	1	12 in.	10 ft
D-9	0	11	3.3 in.	2 ft
D-10	0	11	3.3 in.	10 ft
D-11	0	11	15 in.	2 ft
D-12	0	11	15 in.	10 ft
D-13	45	1	0.3 in.	2 ft
D-14	45	1	0.3 in.	10 ft
D-15	45	1	12 in.	2 ft
D-16	45	1	12 in.	10 ft
D-17	45	11	3.3 in.	2 ft
D-18	45	11	3.3 in.	10 ft
D-19	45	11	15 in.	2 ft
D-20	45	11	15 in.	10 ft

*Extension beyond y = 0.

Several of the simulations exhibit what would normally be considered undesirable patterns as a result of poor design. For example, figure C-8 simulates a single dipole placed 10 wavelengths above the flat plate (normally a dipole would be placed either very close to or very far away from a conducting plane). Nevertheless, the simulation reveals that the nulls actually exist and the only appreciable error in the 75-foot measurement is in the null locations.

It cannot be overemphasized that this study is only a simulation and a very simplified one at that. Shortcomings of this simulation include:

- Edge effects have been ignored.
- The radial component of the electric field has been ignored.
- The flat plate is a poor approximation of the complex shape of a vehicle.
- Radiation off the back of the dipole array has been assumed to be zero, when in fact there will always be some back lobe radiation from the reflector antenna this was intended to simulate.
- The receiving characteristics of the probe antenna have been oversimplified.
- Multiple reflections have been ignored.
- Mutual coupling effects have been ignored.

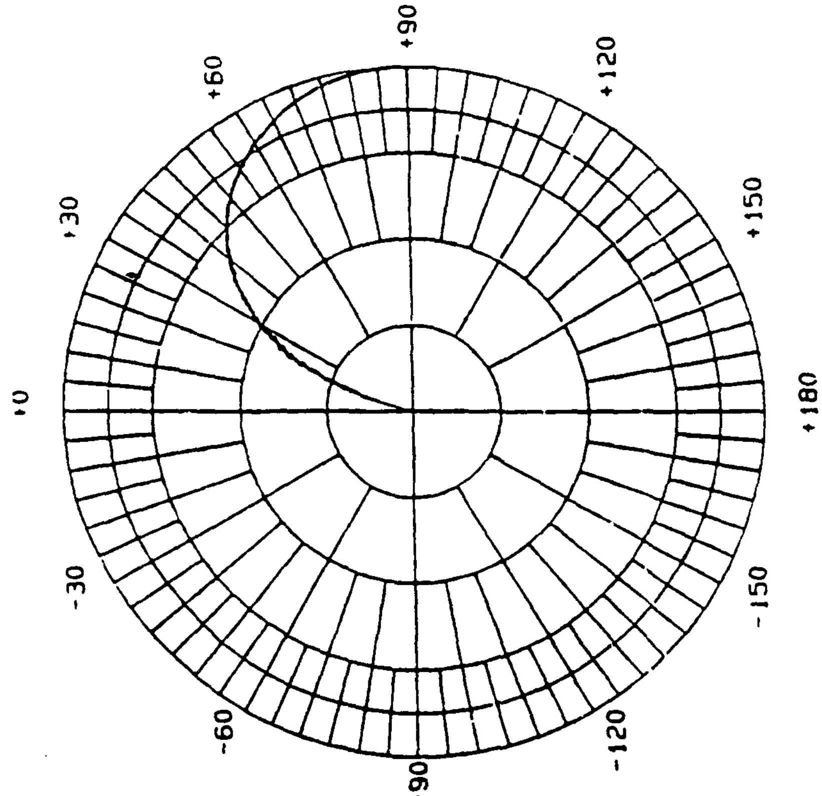

Figure C-6. $\alpha = 0°$, no. of dipoles = 1
height above plate (h) = 0.3 in.
length of plate (l) = 10.0 ft.

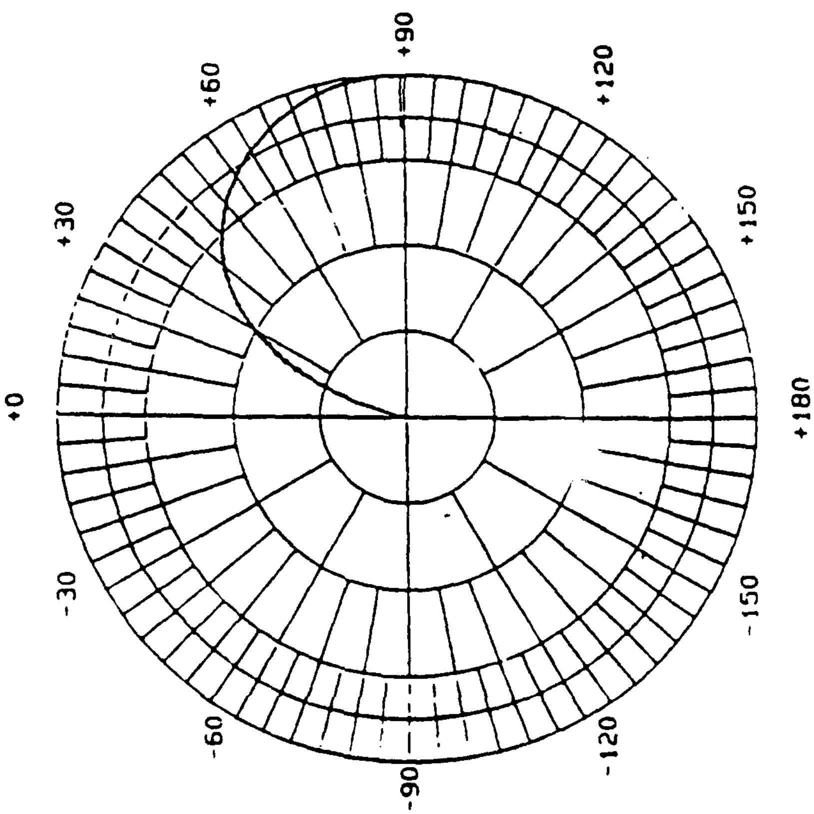

Figure C-5. $\alpha = 0°$, no. of dipoles = 1
height above plate (h) = 0.3 in.
length of plate (l) = 2.0 ft.

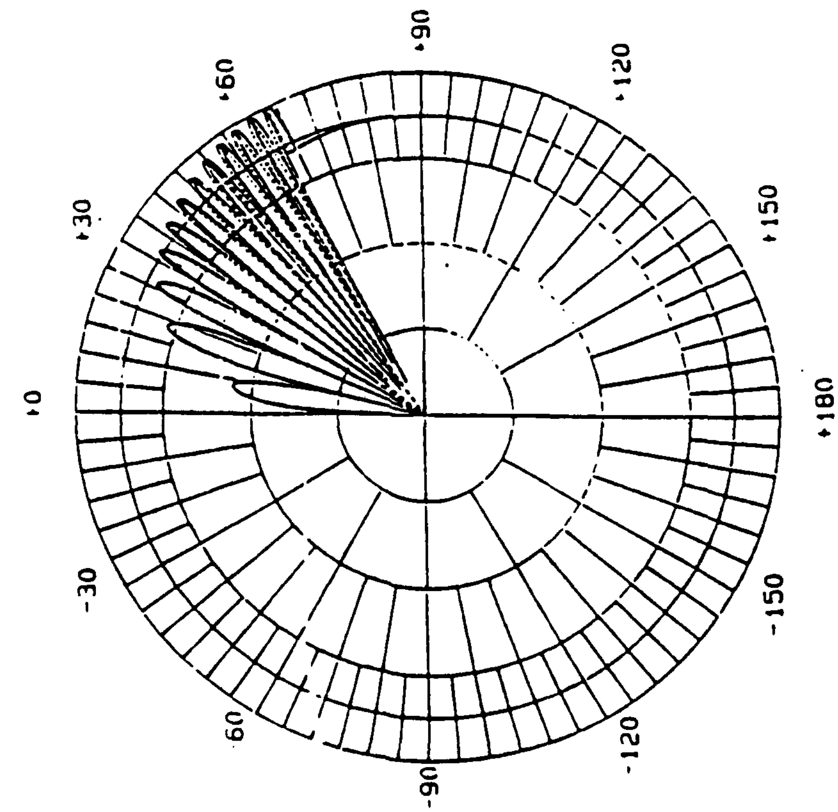

Figure C-7. $\alpha = 0°$, no. of dipoles = 1
height above plate (h) = 12.0 in.
length of plate (l) = 2.0 ft.

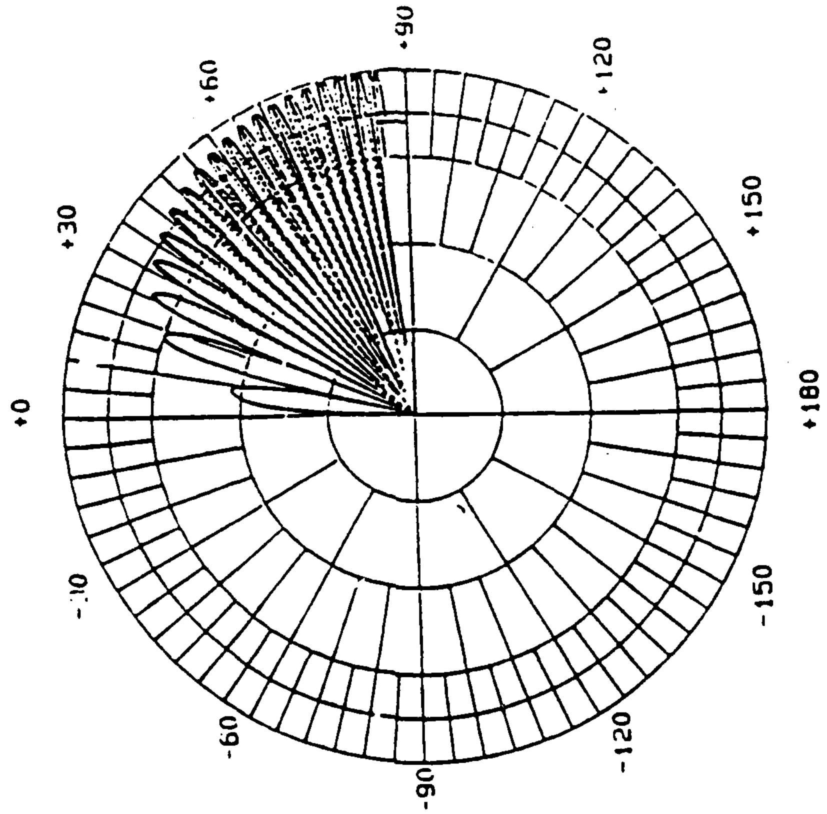

Figure C-8. $\alpha = 0°$, no. of dipoles = 1
height above plate (h) = 12.0 in.
length of plate (l) = 10.0 ft.

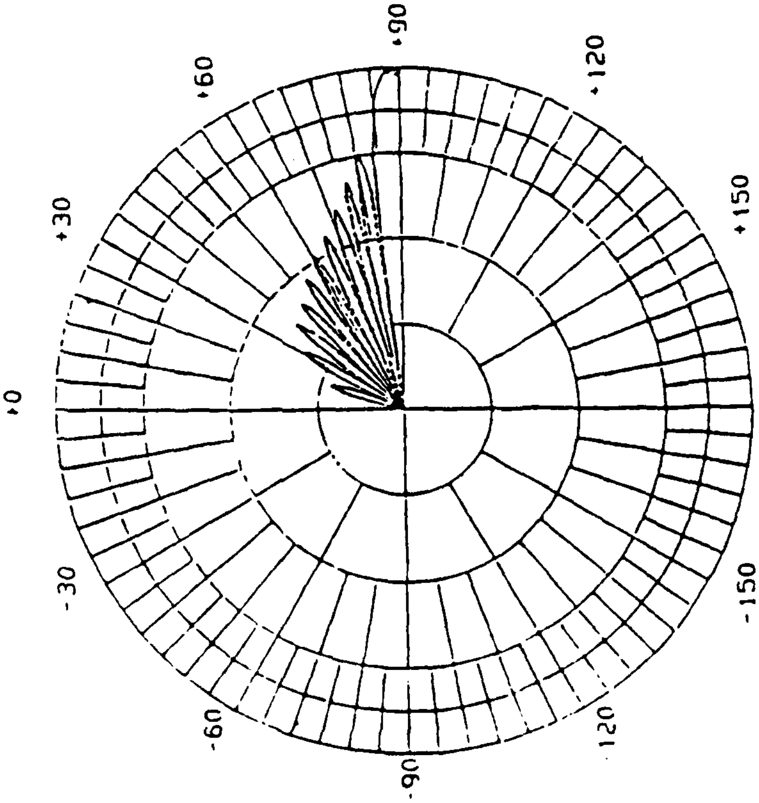

Figure C-9. α = 0°, no. of dipoles = 11
height above plate (h) = 3.3 in.
length of plate (l) = 2.0 ft.

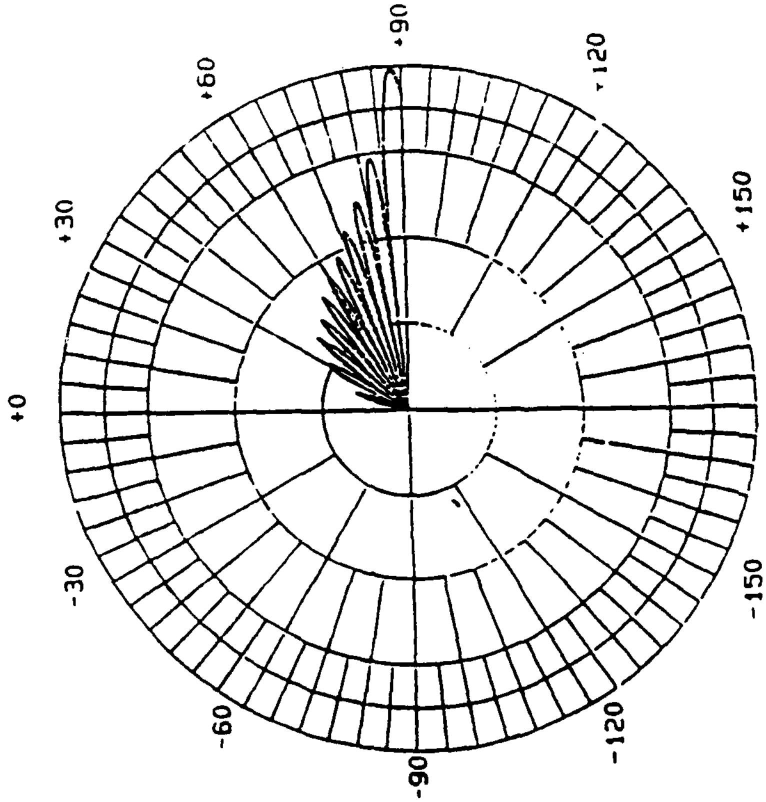

Figure C-10. α = 0°, no. of dipoles = 11
height above plate (h) = 3.3 in.
length of plate (l) = 10.0 ft.

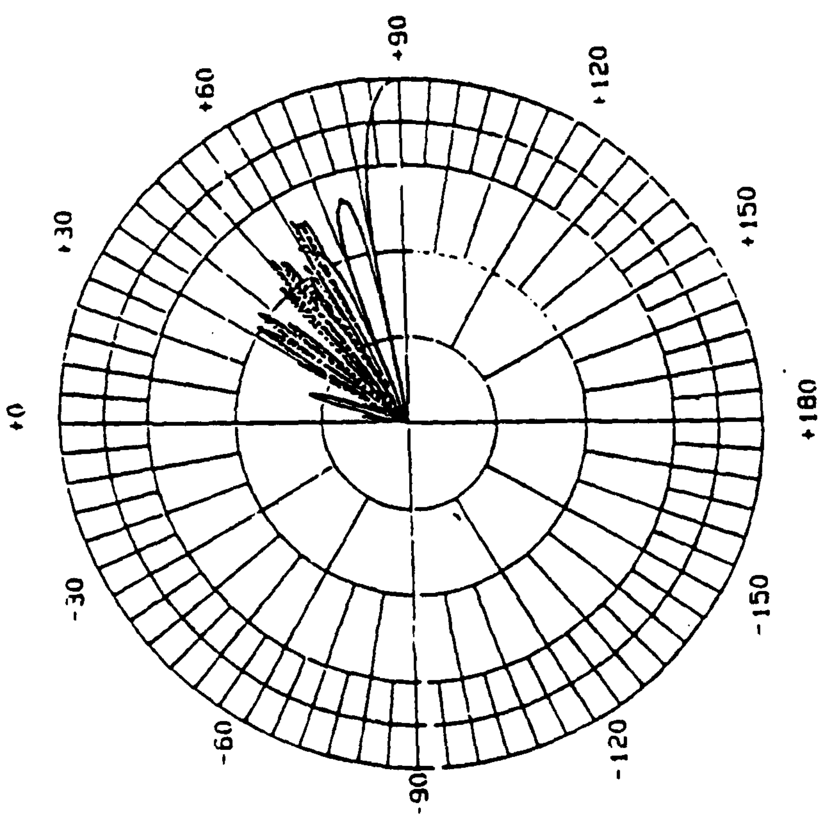

Figure C-11. α = 0°, no. of dipoles = 11
height above plate (h) = 15.0 in.
length of plate (l) = 2.0 ft.

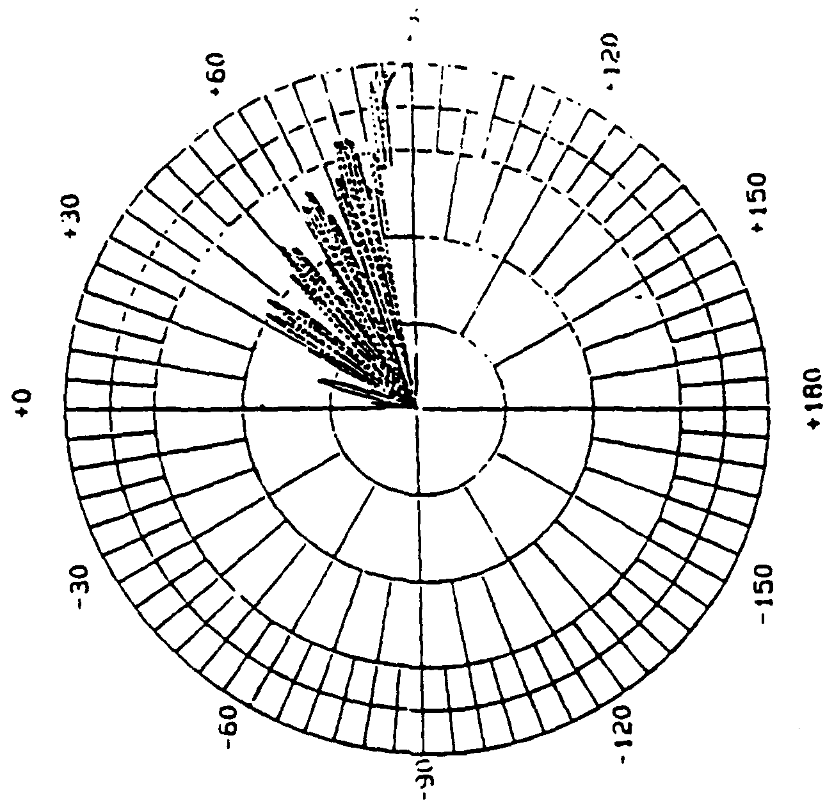

Figure C-12. α = 0°, no. of dipoles = 11
height above plate (h) = 15.0 in.
length of plate (l) = 10.0 ft.

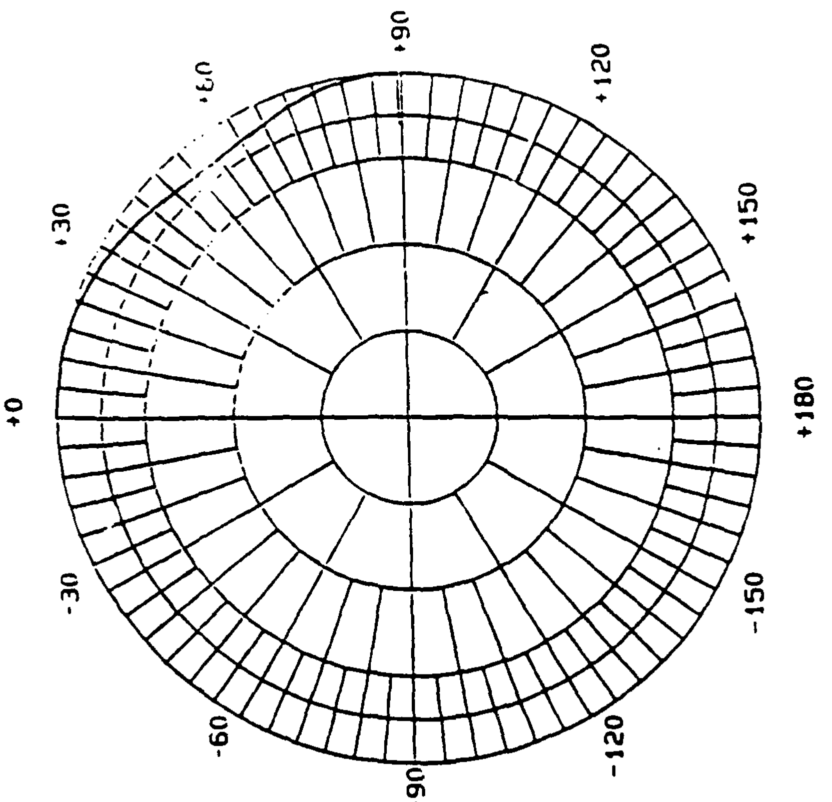

Figure C-14. α = 45°, no. of dipoles = 1
height above plate (h) = 0.3 in.
length of plate (l) = 10.0 ft.

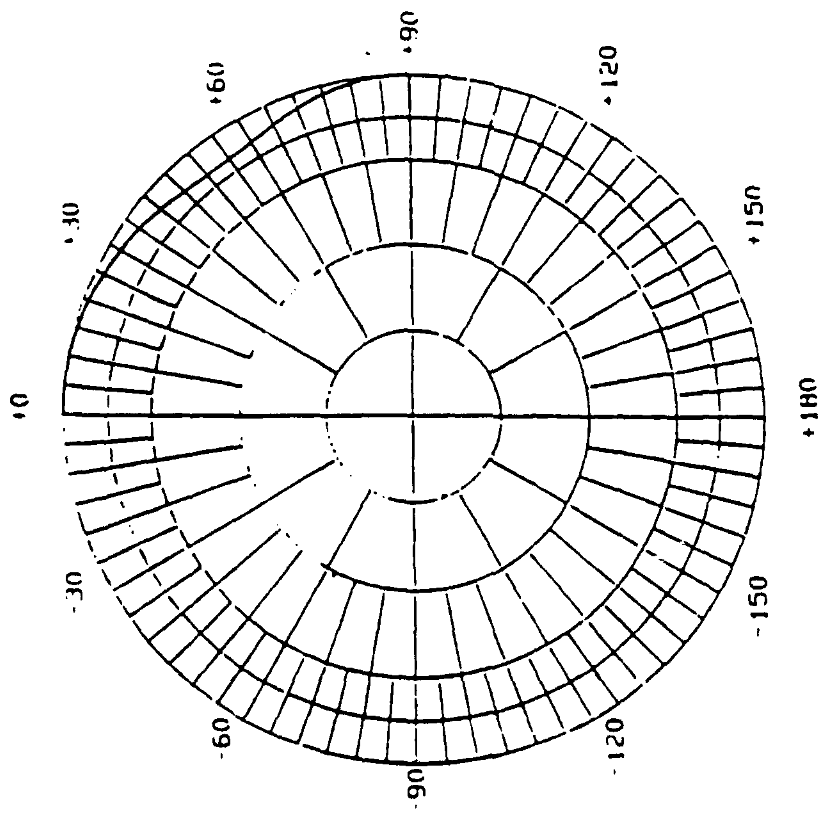

Figure C-13. α = 45°, no. of dipoles = 1
height above plate (h) = 0.3 in.
length of plate (l) = 2.0 ft.

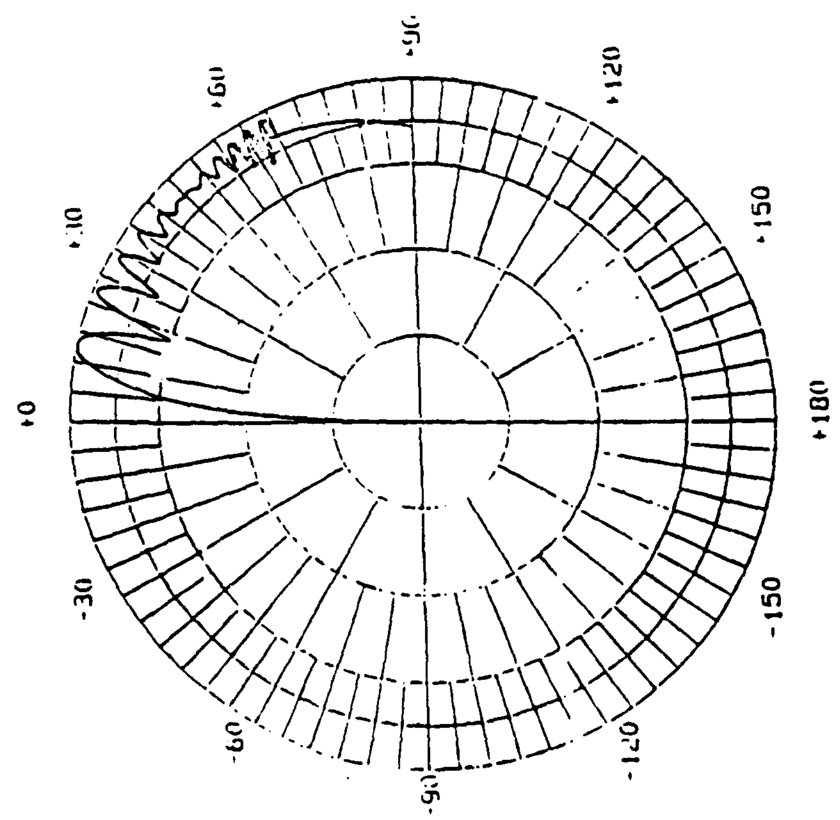

Figure C-15. α = 45°, no. of dipoles = 1
height above plate (h) = 12.0 in.
length of plate (l) = 2.0 ft.

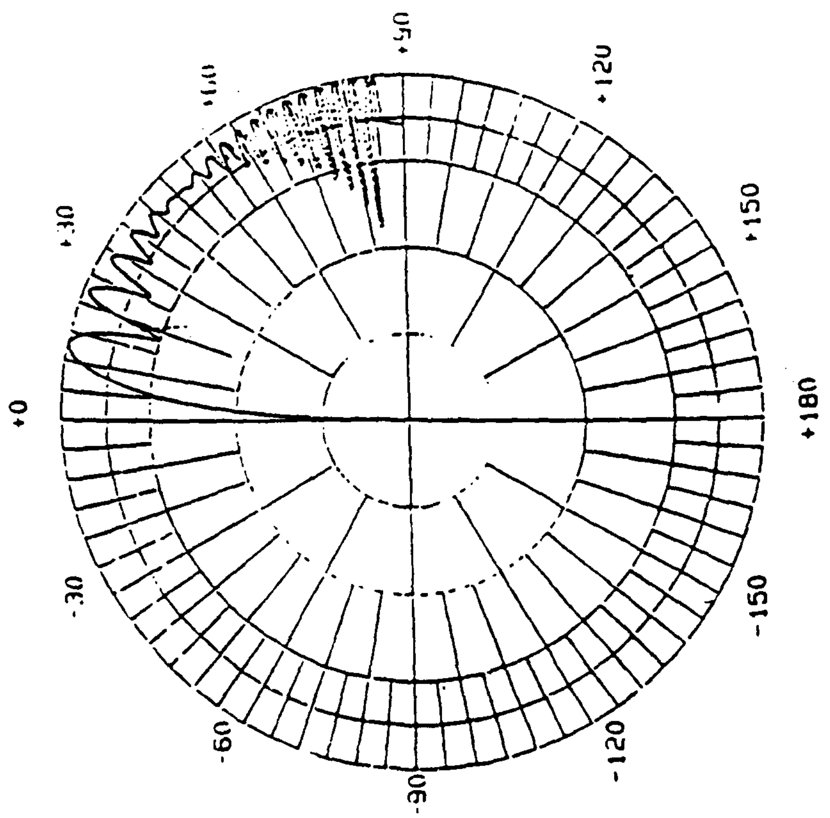

Figure C-16. α = 45°, no. of dipoles = 1
height above plate (h) = 12.0 in.
length of plate (l) = 10.0 ft.

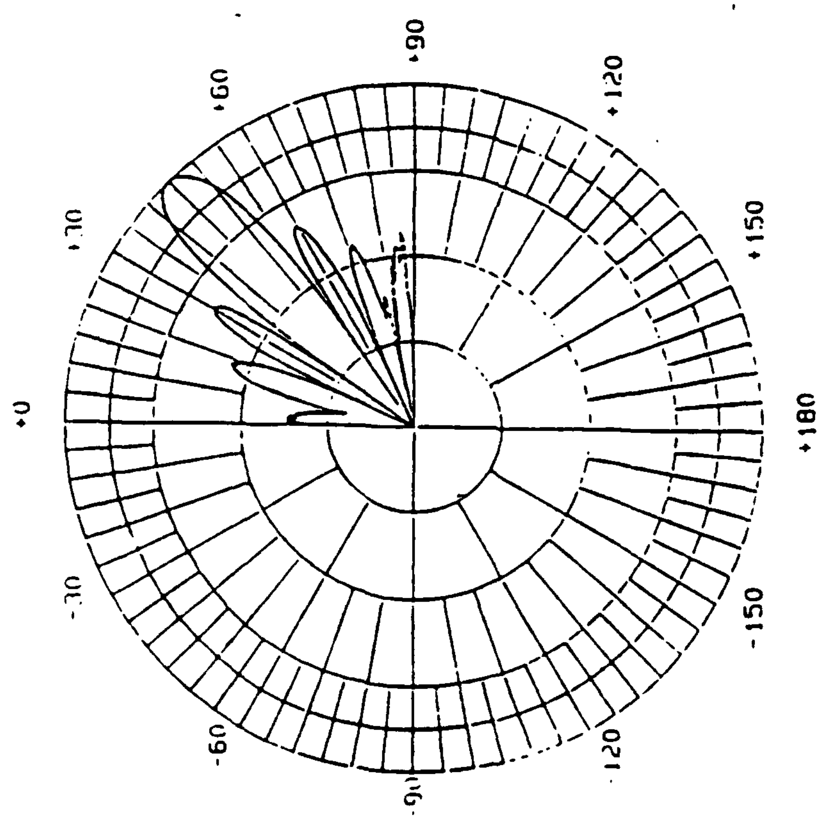

Figure C-17. α = 45°, no. of dipoles = 11
height above plate (h) = 3.3 in.
length of plate (l) = 2.0 ft.

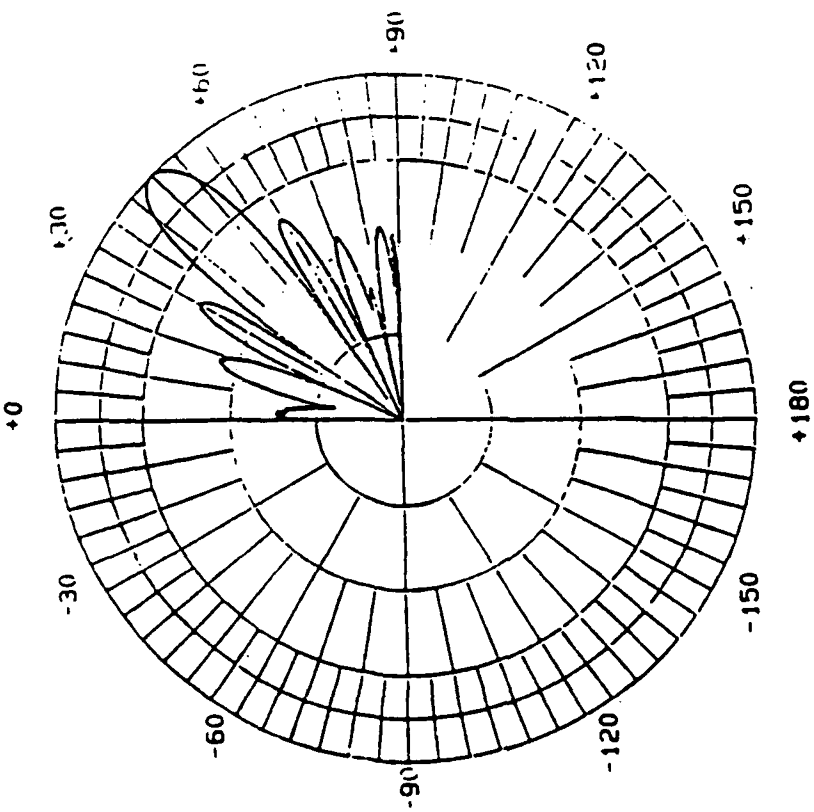

Figure C-18. α = 45°, no. of dipoles = 11
height above plate (h) = 3.3 in.
length of plate (l) = 10.0 ft.

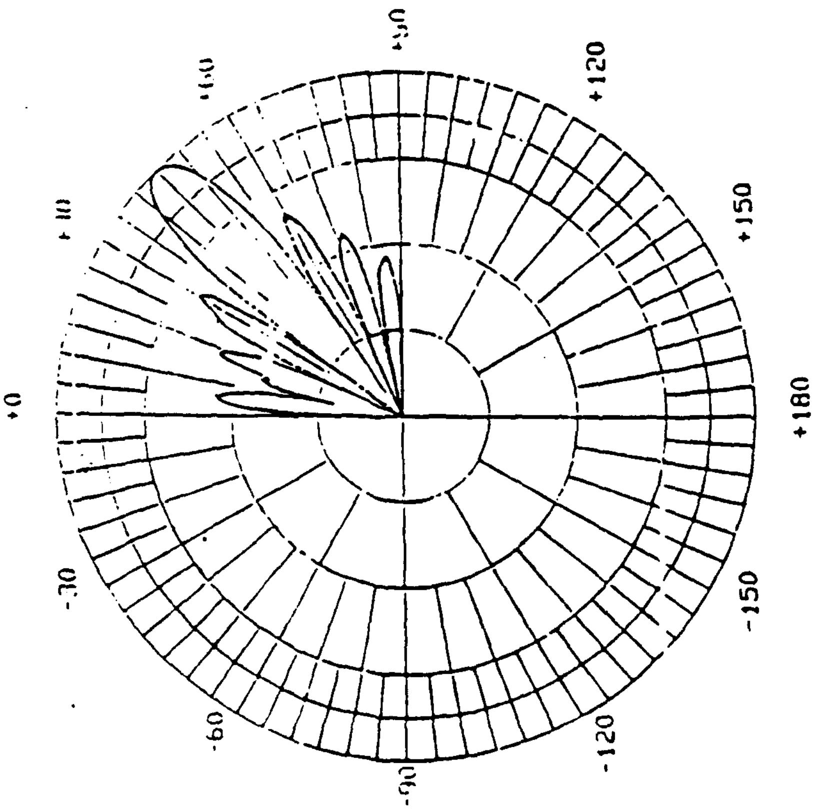

Figure C-19. α = 45°, no. of dipoles = 11
height above plate (h) = 15.0 in.
length of plate (l) = 2.0 ft.

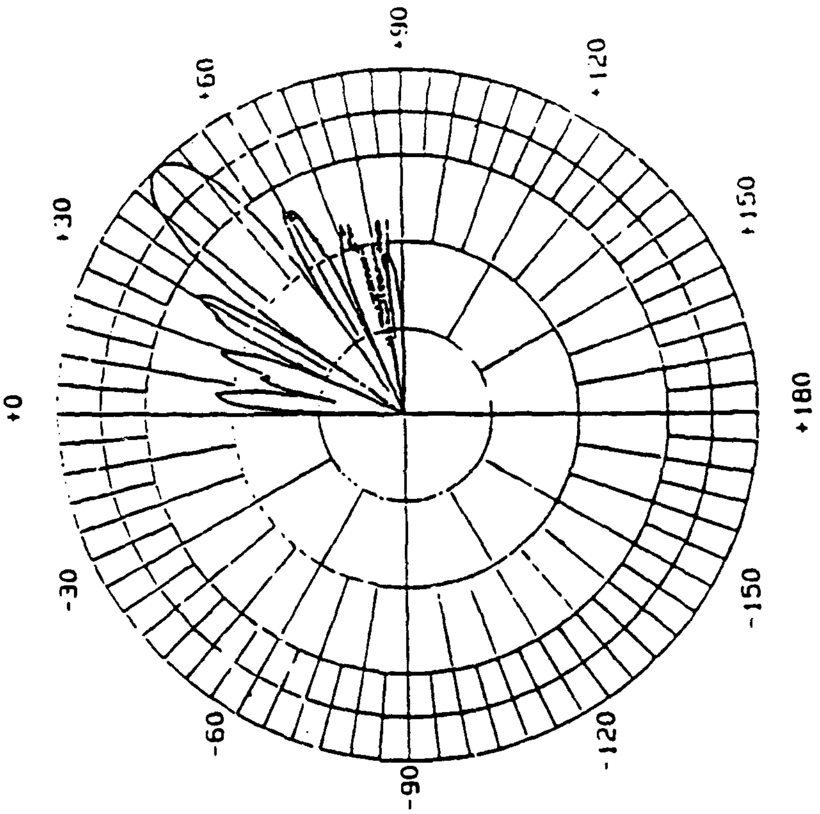

Figure C-20. α = 45°, no. of dipoles = 11
height above plate (h) = 15.0 in.
length of plate (l) = 10.0 ft.

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APPENDIX D. ABBREVIATIONS

ADAAS	Automated Data Acquisition and Analysis System
ANSI	American National Standards Institute
ATF	Antenna Test Facility
AZ	azmiuth
dB	decibel(s)
dBi	decibel(s) referenced to isotropic
dBm	decibel(s) referenced to a milliwatt
DEC	Digital Equipment Corporation
EL	elevation
F	Fahrenheit
GHz	gigahertz
HIU	hydraulic interface unit
IEEE	Institute of Electrical and Electronic Engineers
IF	intermediate frequency
LO	local oscillator
MHz	megahertz
RF	radio frequency
SA	Scientific Atlanta
SCR	silicon controlled rectifier
TECOM	US Army Test and Evaluation Command
TOP	test operations procedure
TWT	travelling wave tube
USAEPG	US Army Electronic Proving Ground

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